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APEX: RADIOMETRY UNDER SPECTRAL SHIFT CONDITIONS

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ABSTRACT

The APEX airborne imaging spectrometer has been shown to exhibit spectral shifts during in-flight conditions, linked to changes in the nitrogen gas density within the APEX optical subunit. These shifts lead to features in the recorded spectra caused by the dichroic coating used as a beam splitter between VNIR and SWIR channels. Consequently dichroic features are no longer compensated for by the radiometric calibration coefficients obtained under laboratory conditions. This paper presents results of a numerical simulation that can model the impact of spectral shifts on radiometry. As a consequence the APEX sensor model has been upgraded and according correction functions have been implemented in the APEX level 1 processor to compensate for shift dependent changes in radiometry due to the dichroic coating.

***Index Terms*—** Airborne Imaging Spectroscopy, Instrument Calibration, Spectral Shifts

1. INTRODUCTION

ESA's Airborne Imaging Spectrometer APEX (Airborne Prism Experiment) was developed under the PRODEX (PROgramme de Développement d'EXpériences scientifiques) program by a Swiss-Belgian consortium and entered its operational phase at the end of 2010. It features up to 532 spectral bands in full spectral mode with data being recorded by two optical channels that are split at the SWIR prism using a dichroic coating [1-3].

The generation of high quality data products from imaging spectrometer data requires an accurate instrument model that allows the proper calibration of data during level0-level1 processing [4]. During calibration and validation exercises carried out in the commissioning and current operational phases of APEX it became obvious that the current instrument model missed some component, as unknown features appeared in the calibrated radiance data that could not attributed to target or atmospheric properties. Fig. 1 illustrates such a features, here in the spectral signature of a vegetation target.

A thorough analysis of the effect revealed a dependency of the magnitude of the feature on the flight altitude. This led to the hypothesis that the artifact was created due to spectral shifts that were shown to occur during flight operations, largely explained by flight altitudes [5, 6], in combination with the spectral characteristics of the dichroic coating.

This paper describes the effects of the coating on the radiometry under the influence of spectral shifts that occur during flight operations. To this end, a discrete numerical simulation was developed to model the resulting digital numbers and calibrated radiances for a range of spectral shifts. Furthermore, the APEX data processor was upgraded to compensate for these effects.

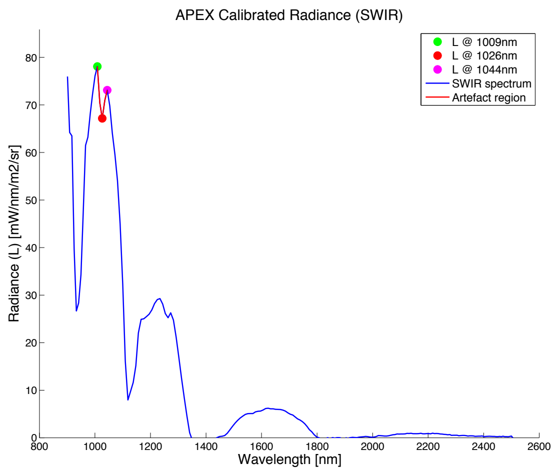

Fig. 1: Example of an unexpected feature appearing in the 1030nm region of the SWIR detector

2. METHODS

2.1. APEX Channel Splitting by Dichroic Coating

The APEX optical chain features a single imaging slit, requiring a beam splitting into VNIR and SWIR channels within the instrument after the slit. This is accomplished by a dichroic coating (DIC) applied to the SWIR prism, effectively transmitting the SWIR wavelengths while reflecting the VNIR spectrum towards the VNIR prism.

The nominal DIC transmissions supplied by industry [7] show both spectral and polarisation dependencies (Fig. 3). Within this paper, we shall focus on the spectral characteristics in the unpolarised case.

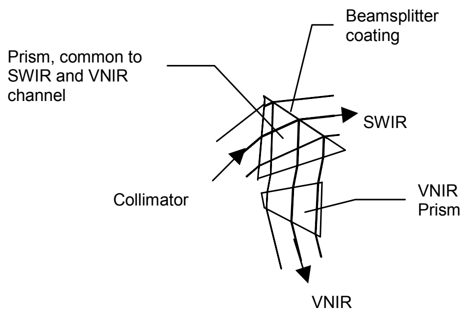

Fig. 2: Prisms and channel splitting in the APEX Optical Sub Unit [7]

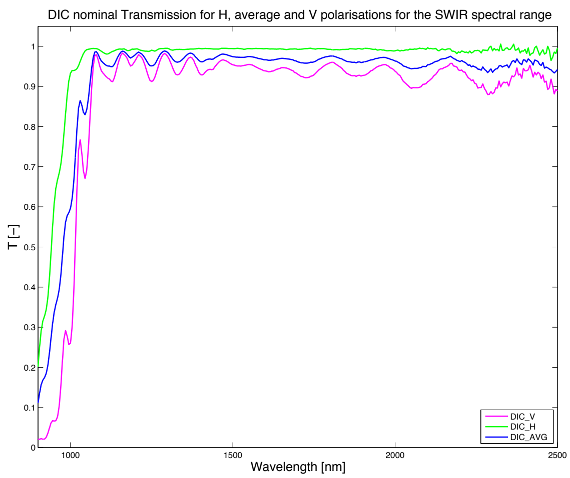

Fig. 3: Nominal transmittance of the DIC for vertical, horizontal and average polarisations

2.2 Simulation of the Sensor Response under Spectral Shift Conditions

The simulation bases on spectral shift characteristics estimated from laboratory experiments carried out at the APEX Calibration Home Base (CHB) at DLR, Oberpfaffenhofen, Germany [8]. Using these data a sensor model is utilized to model the impact of the convolved DIC transmission on the recorded digital numbers for a large number of spectral shifts that cover the shift range occurring during actual in-flight conditions. Essentially an at-sensor radiance is modified by the dichroic coating transmission and then convolved by a shifted APEX sensor, leading to digital numbers that would be recorded by the system for a particular shift. These simulated digital numbers are then calibrated to radiances by applying the APEX nominal, i.e. laboratory based radiometric calibration coefficients.

2.3 Compensation of the Effect

The errors introduced by spectral shifts to the radiometry require a correction during data processing and according algorithms have been added to the APEX level1 processor, which remove the effects to about the level of the uncertainty of the radiometric calibration under laboratory conditions, currently estimated to be about 4% on average.

The correction of the DIC is an iterative process. In a first step a standard radiometric correction is a applied to the data and the resulting radiance cube is fed into ATCOR [9] to estimate the spectral shift. These shifts are used in a second iteration within the APEX level 1 processor to select one pre-calculated simulated shift realisation using a root mean square minimization. The selected realisation is then used to calculate a factor that transforms the dichroic features from a shifted to an unshifted case. This transformation is applied to the DNs. The DNs are subsequently radiometrically calibrated using the CHB based radiometric coefficients. Remaining DIC features can optionally be removed by fitting a convex hull to the most affected spectral bands between 950nm – 1050nm.

3. RESULTS

The results of the simulation not only confirm the hypothesis that spectral shifts in combination with the spectral features of the dichroic coating do lead to the observed radiometric errors but also manifest the large impact on the radiometry such spectral shifts can have when assuming a maximum shift of ±2.5 pixels. The impact on the digital numbers may appear marginal on first sight.

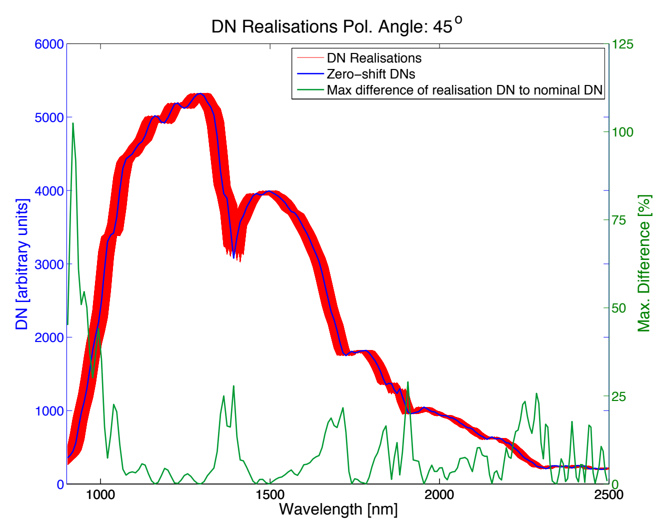

Fig. 4. Comparison of unshifted DN sensor response with DN simulations for spectral shifts up to ±2.5 pixels and the resulting maximum percent difference

However, the percent difference is showing the impact of the spectral shifts, particularly at the start of the detector coinciding with the high gradient of the DIC and leading to differences of up to 102% (Fig. 4). The impact on radiometry is however obvious after radiometric data calibration where the spectra fan out between 900nm and 1100nm (Fig. 5).

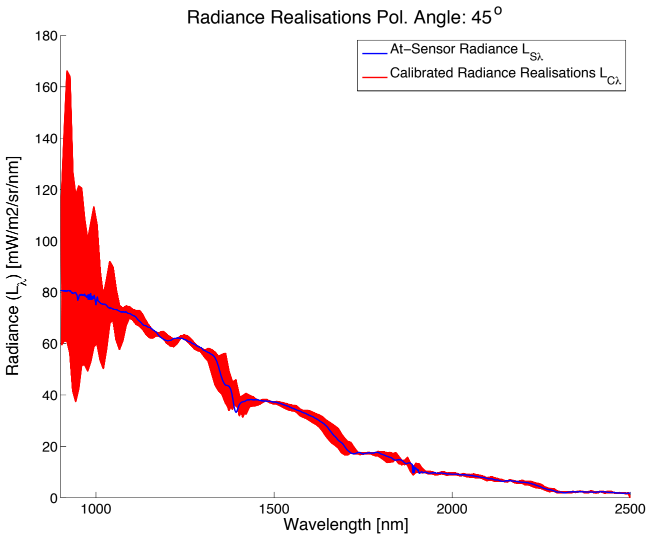

Fig. 5. Comparison of at-sensor radiance with calibrated radiances simulations for spectral shifts up to ±2.5 pixels

Applying the DIC correction to APEX image data during level 1 processing leads to a significant reduction of features caused by the DIC while remaining undulations can be removed by using a convex hull smoothing approach (Fig. 6). As expected the correction is largest for the first few bands of the SWIR till 1070nm, coinciding with the high gradient of the DIC transmission in that region. The impact of the correction on the most affected region is shown in Fig. 7. The application of the convex hull smoothing may of course remove some true features. The impact of the smoothing on the information content can be assessed using the DIC simulation presented in this paper. However, there is a remaining uncertainty due to errors in the spectral shift retrieval and due to differences between the assumed system transmission used for the simulation and true transmission of the actual instrument. Assessing the latter is complicated by the implicit spectral convolution by APEX. An alternative option to assess the quality of the DIC correction is to use spectral ground truth to compute at-sensor radiances using radiative transfer tools such as Modo [10] followed by a spectral convolution.

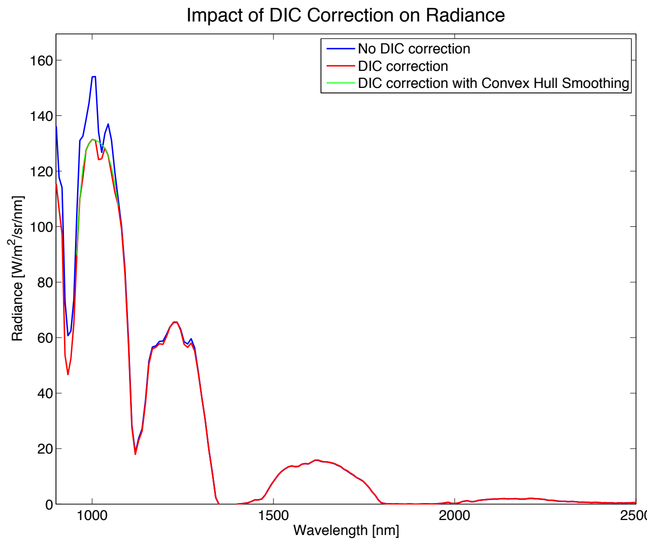

Fig. 6: Result of the DIC correction on a vegetation spectrum acquired by APEX

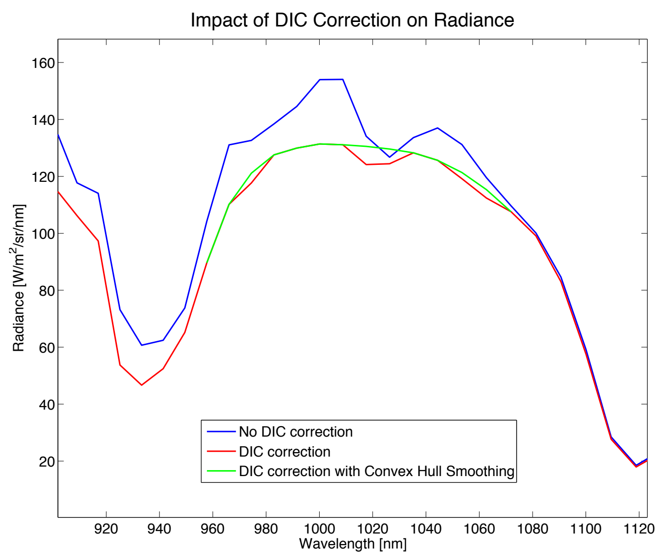

Fig. 7: Zoom of the spectral region of the SWIR most affected by the DIC transmission and results of the correction applied in level 1 processing

4. CONCLUSIONS

The findings of this study led to a substantial upgrade of the APEX sensor model, calibration information system [11] and level1 processor [4], making improved radiance products available to the end-users by the end of 2013. Furthermore, we must conclude that similar effects might appear in other sensor systems as well whenever the optical chain comprises some optics with spectral features that in combination with spectral shifts may lead to significant changes in radiometry.

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